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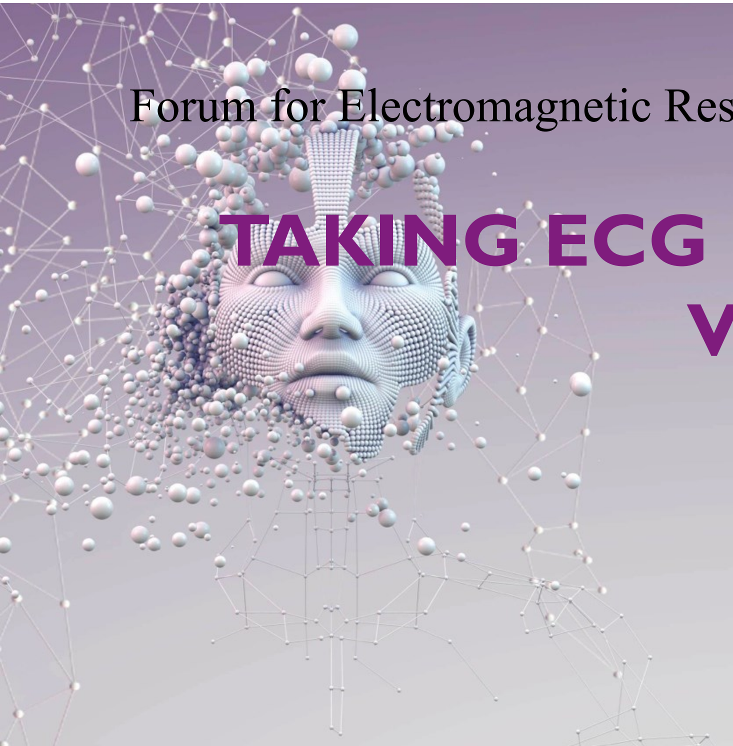

TAKING ECG SIGNALS FROM A HUMAN VOXEL MODEL

HUBREGT J.VISSER

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ABSTRACT

First results on applying CST Microwave Studio in combination with a human voxel model and a dedicatedly developed equivalent cardiac cycle source are reported. Based on first coarse-meshing simulation results it may be concluded that it is feasible to model the heart in a three-dimensional anthropomorphic voxel model of a human being by an equivalent fixed dipole volume source. Through changing the amplitude and orientation over the cardiac cycle, ECG signals may be obtained from the chest area of the voxel model.

Keywords—dipole; heart; ECG; voxel model

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1. Introduction
2. Volume Conductor Modeling
3. Equivalent Volume Source Model
4. Fixed Dipole Model and Implementation
5. First Simulation Results
6. Summary
7. Conclusions

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1. INTRODUCTION

The Problem

- **How to determine Electro Cardio Graphic (ECG) probe positions on the body?**
- **How to combine this with radio?**

↓

Need for model

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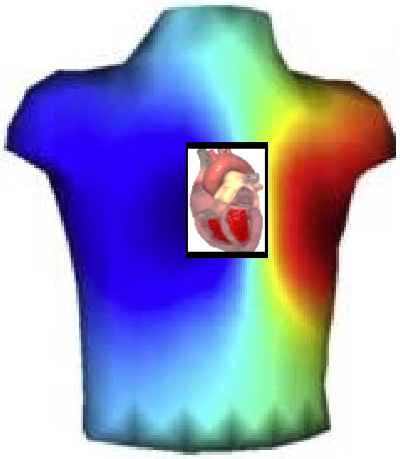
1. INTRODUCTION

Forward and Inverse Problem of Cardiography



- In electrocardiography (ECG), the condition of the heart is monitored through measuring the body surface potential;
- Measurements are typically taken on the torso;
- Through a model, the body surface potential is related to the epicardial potential = inverse problem;

- For solving the inverse problem the forward problem needs to modeled = relating epicardial to body surface potential;
- From the body surface potential distribution, the body surface charge and current distributions may be determined.

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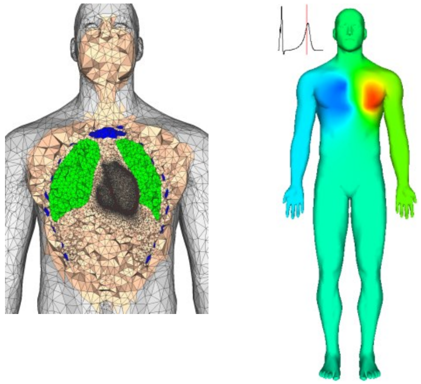
1. INTRODUCTION

The Forward Problem

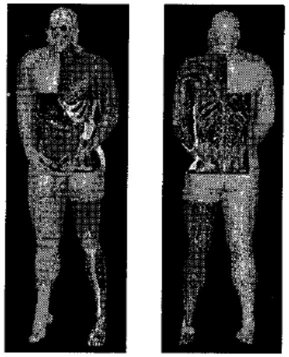
- Surface modeling: Only boundaries between dielectric regions are modeled, regions are considered to be isotropic;

- Volume modeling: The only way to incorporate regions of anisotropic conductivity (organs, arteries, bones).

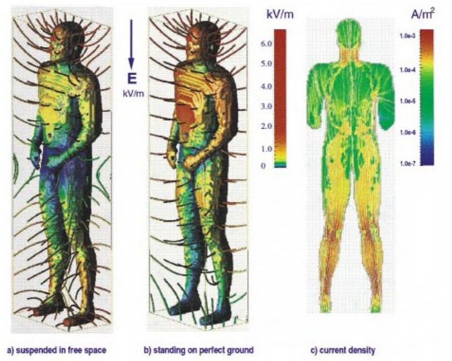
Numerical computation techniques:



Finite Elements (FE)*



Finite Difference Methods (FDM)**


E
kV/m
kV/m
6.0
5.0
4.0
3.0
2.0
1.0
0
A/m²
1.0e-3
1.0e-4
1.0e-5
1.0e-6
1.0e-7
a) suspended in free space
b) standing on perfect ground
c) current density

Finite Difference Time Domain (FDTD)***

---

*M.A. Fernandez and N. Zemzemi, 'Decoupled Time-Marching Schemes in Computational Cardiac Electrophysiology and ECG Numerical Simulation', *Mathematical Biosciences*, Vol.226, No.1, pp.58-75, 2010.

**F.B. Sachse, C.D. Werner, K. Meyer-Waarden and O. Doessel, 'Solving the Forward Problem in Electrocardiography: Analysing the Selection of Appropriate Regions of Impedance Models', *Computers in Cardiology*, Vol.25, pp.701-704, 1998.

***M.A. Stuchlyand T.W. Dawson, 'Interaction of Low-Frequency Electric and Magnetic Fields with the Human Body'. *Proceedings of the IEEE*, Vol. 88, No. 5, pp. 643-664, May 2000.

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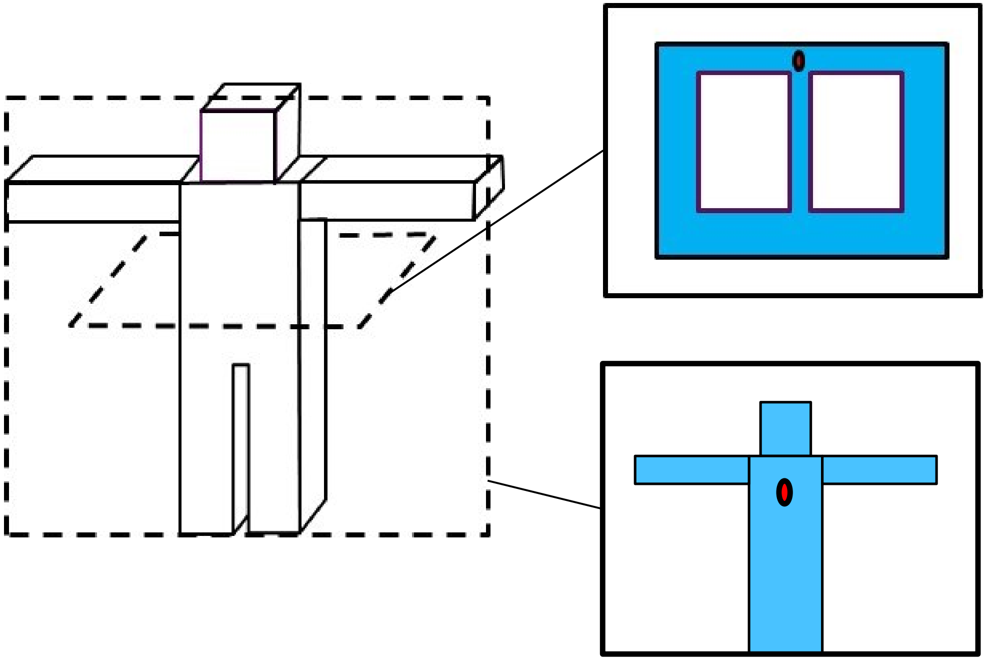
2. VOLUME CONDUCTOR MODELING

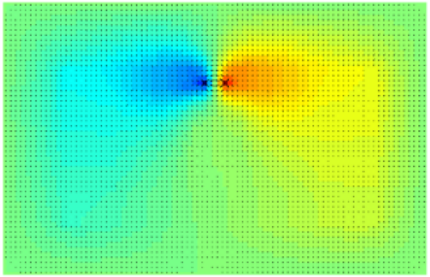
Finite Difference Method (FDM)

- Ease of implementation;
- Computational efficient;
- Gradual model refinement.

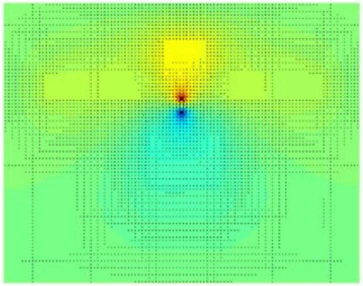
2D → 3D → inhomogeneity



Surface potential



± 1V dipole, lossless dielectric



± 1V dipole, lossless dielectric

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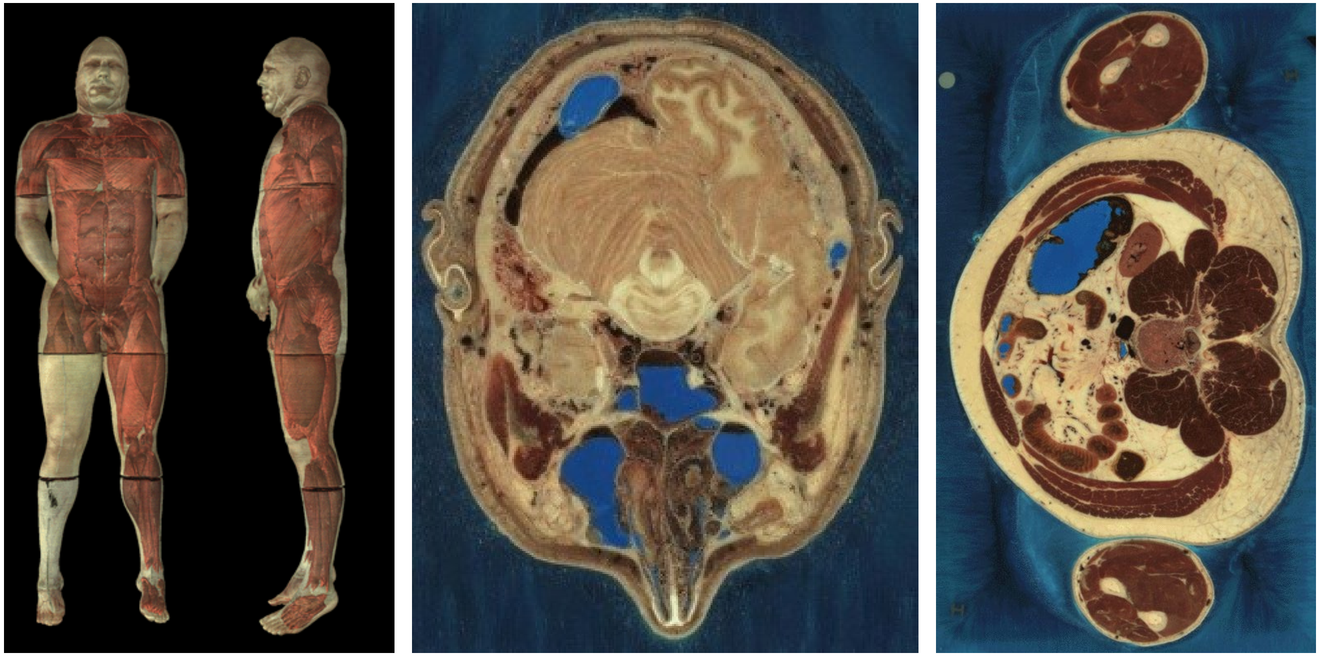
2.VOLUME CONDUCTOR MODELING

FDM - Visible Human Project

- US National Library of Medicine (NLM) dataset of cross-sectional photographs of human body



- Correct dielectric characteristics assigned to all organs*
- Voxels (volume pixels) of 1mm x 1mm x 1mm created
- Visual Man body (parts) may be included in 3D FDM code

*J.W. Massey, *Creating AustinMan: An Electromagnetic Voxel Model of the Visible Human*, Undergraduate Thesis, University of Texas at Austin, May 2011.

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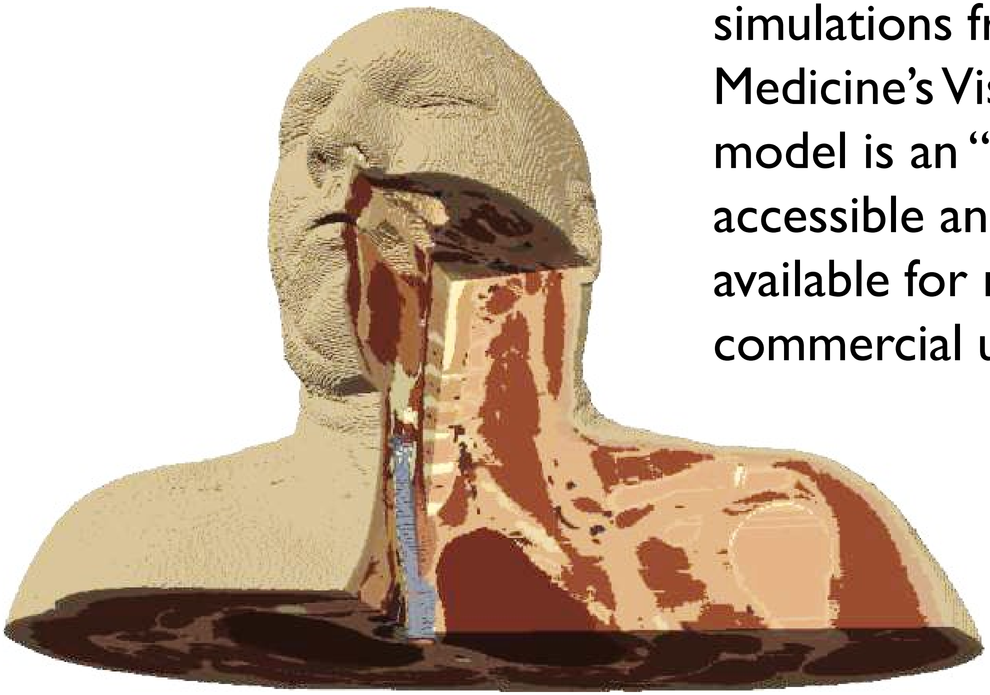
2. VOLUME CONDUCTOR MODELING

Visible Human Project – AustinMan



AustinMan is a voxel model of the human body that is being developed for electromagnetic simulations from the National Library of Medicine's Visual Human Man data set. The model is an "open model" that is easily accessible and verifiable. The model is freely available for research, teaching, or other non-commercial uses.

AustinMan Electromagnetic Voxel models available at http://tiny.cc/AustinMan

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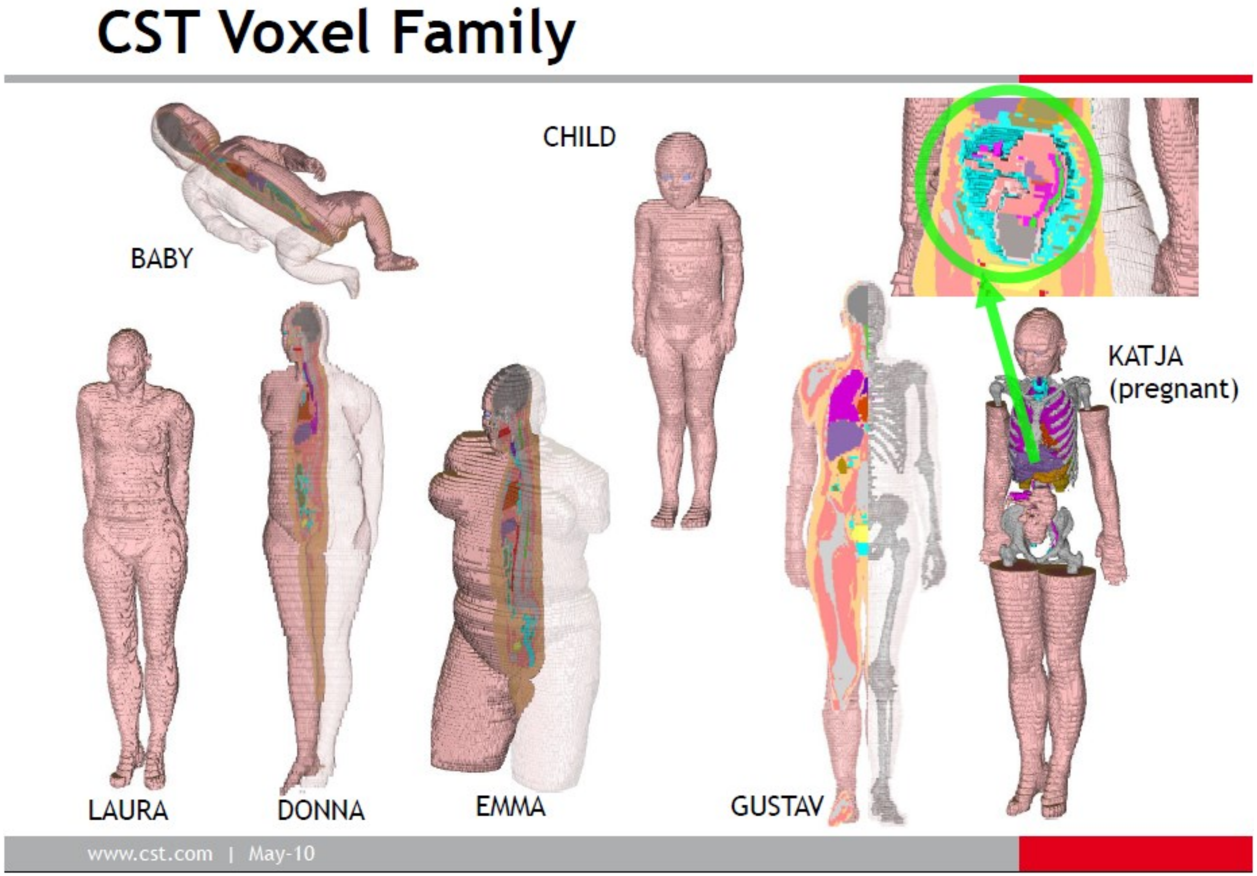
2. VOLUME CONDUCTOR MODELING

CST Voxel Family*



CST Voxel Family

BABY
CHILD
KATJA (pregnant)
LAURA
DONNA
EMMA
GUSTAV

www.cst.com | May-10

Anthropomorphic human models in resolutions ranging from $0.98 \times 0.98 \times 10 \text{mm}^3$ to $2.08 \times 2.08 \times 8.0 \text{mm}^3$

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*CST [Online]. Available at: http://www.cst.com/Content/Events/downloads/eugm2010/Bio-Medical_RF_simulations_with_CST_MICROWAVE_STUDIO.pdf

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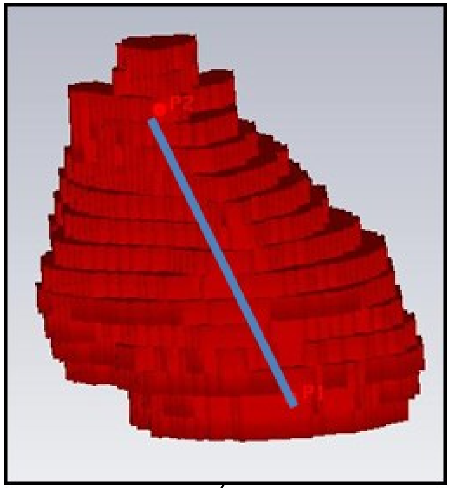
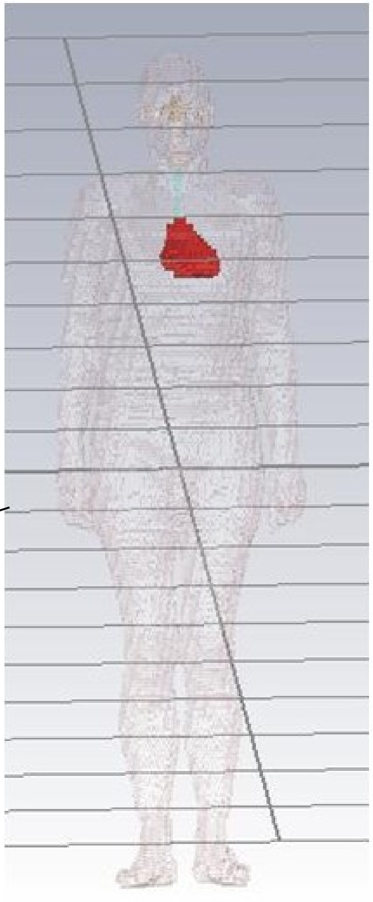
2. VOLUME CONDUCTOR MODELING

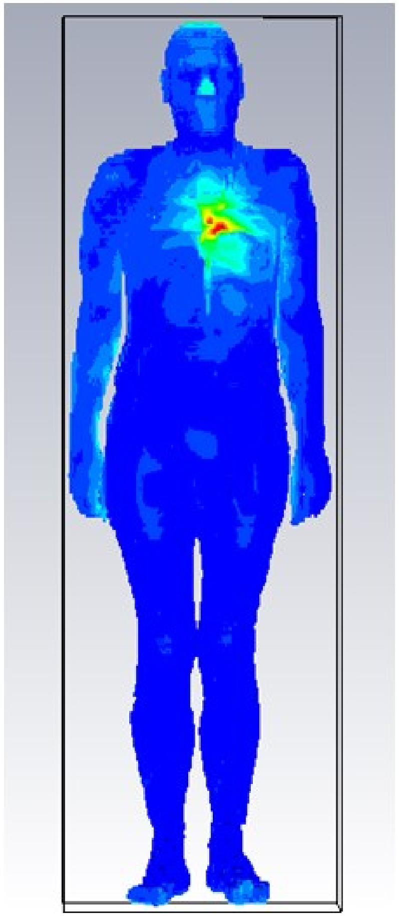
CST Gustav and Dipole Source

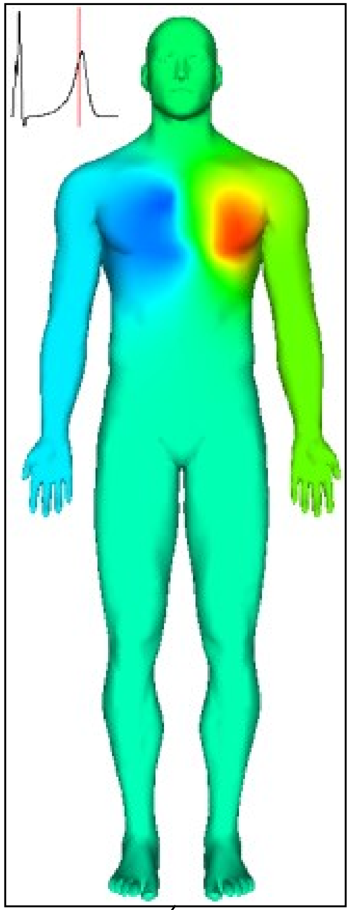
Body surface electric field





Heart activity modeled as a non-rotating 60Hz sinusoidally excited dipole

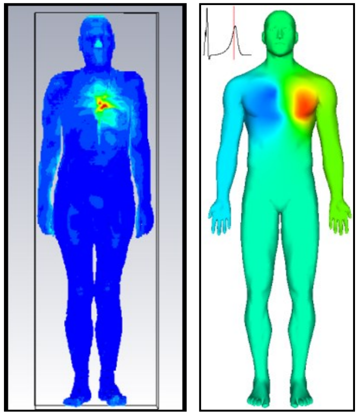




Torso modeled as consisting of heart, lungs bones and remaining tissue*

*M.A. Fernandez and N. Zemzemi, ‘Decoupled Time-Marching Schemes in Computational Cardiac Electrophysiology and ECG Numerical Simulation’, *Mathematical Biosciences*, Vol.226, No.1, pp.58-75, 2010.

3. EQUIVALENT VOLUME SOURCE MODEL



- First body surface electric field results look promising;
- Influence of body details don’t seem to be dominant;
- Equivalent volume source model needed.

Basic source volume models

- **(Fixed) Dipole:** single dipole, variable orientation and magnitude;
- **Moving Dipole:** as above, but also varying position;
- **Multiple Dipoles**;
- **Multipoles**.

- Easy to implement;
- Accounts for 80% of body surface potentials.

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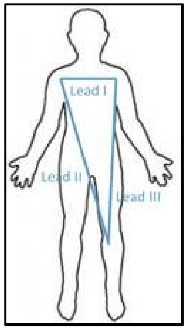
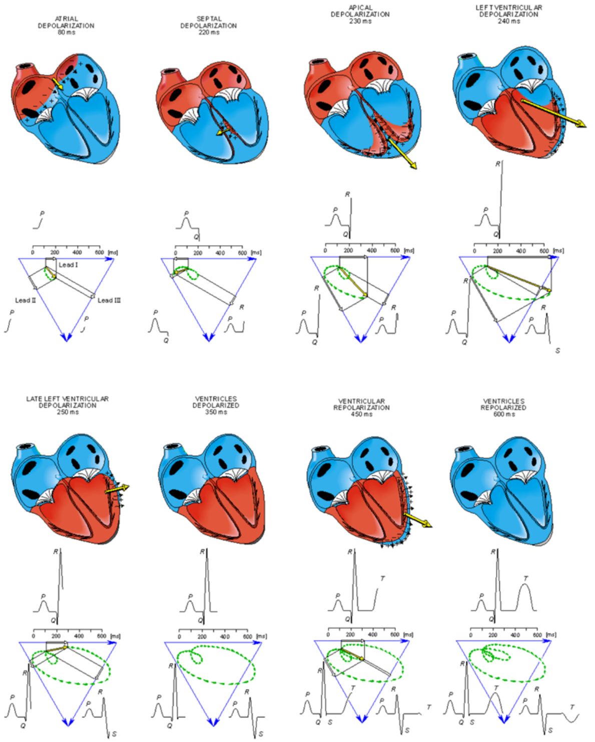
4. FIXED DIPOLE MODEL AND IMPLEMENTATION

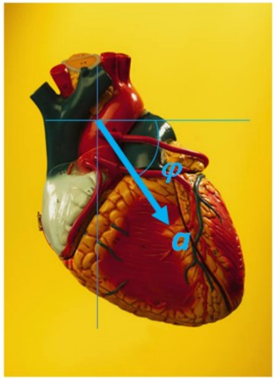
Equivalent Source Model


Lead I
Lead II
Lead III

- From ECG potential differences, measured over the Einthoven triangle leads, a source is constructed;
- We try to find out if we can use this source in a CST voxel model to obtain ECG potential differences.


ATRIAL DEPOLARIZATION 80 ms
SEPTAL DEPOLARIZATION 220 ms
APICAL DEPOLARIZATION 230 ms
LEFT VENTRICULAR DEPOLARIZATION 240 ms
LATE LEFT VENTRICULAR DEPOLARIZATION 250 ms
VENTRICLES DEPOLARIZED 350 ms
VENTRICULAR REPOLARIZATION 450 ms
VENTRICLES REPOLARIZED 600 ms
Lead I
Lead II
Lead III
P
Q
R
S
T

*



time (ms)	*a* (norm.)	*φ* (degrees)
0	0	0
80	1	0
220	1	90
230	2.5	0
240	4	-30
250	1.5	-80
350	0	0
450	2	15
600	0	0
1000	0	0

*J. Malmivuo, R. Plonsey, Bioelectromagnetism, *Principles and Applications of Bioelectric and Biomagnetic Fields*, Oxford University Press, New York, 1995.

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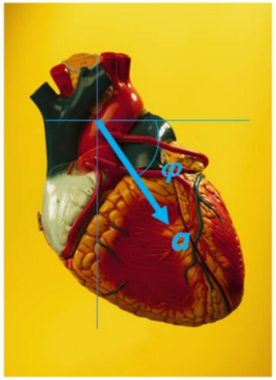
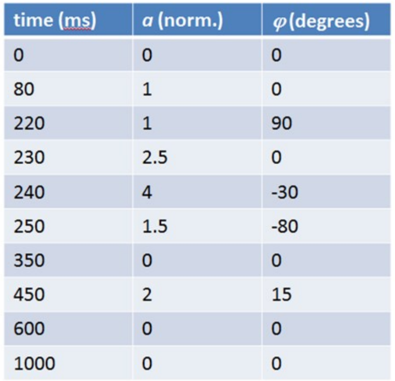
4. FIXED DIPOLE MODEL AND IMPLEMENTATION

Equivalent Source Model





time (ms)	a (norm.)	φ (degrees)
0	0	0
80	1	0
220	1	90
230	2.5	0
240	4	-30
250	1.5	-80
350	0	0
450	2	15
600	0	0
1000	0	0

Implementation in CST voxel model

- Voltage or current paths, having a sinusoidal excitation needed for performing a quasi-magnetostatic analysis;
- Implement low-frequency sinusoidal current path (dipole) with required amplitude and orientation per timestamp;
- Record maximum body surface electric field distribution;
- Take differences for relative ECG signal strength.

Determine cross sectional heart plane in Gustav voxel model

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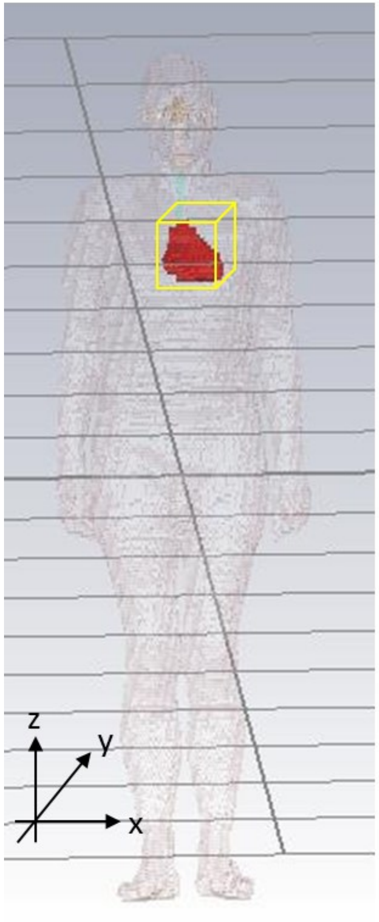
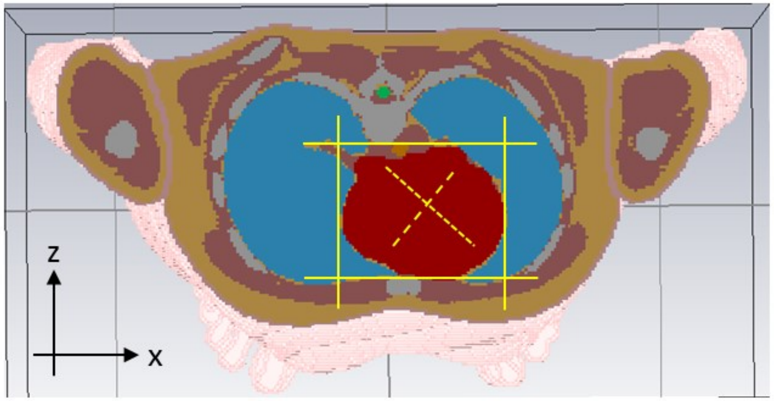
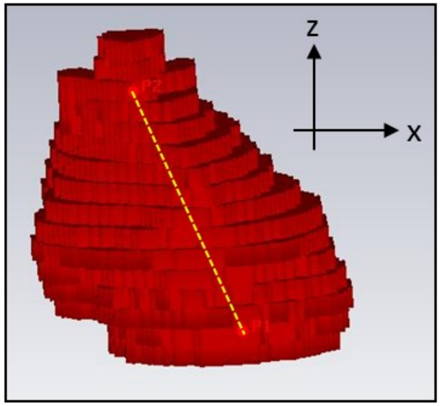
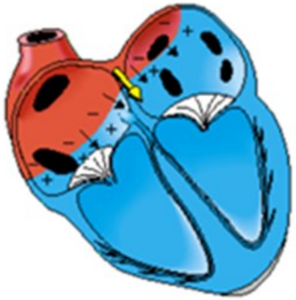
4. FIXED DIPOLE MODEL AND IMPLEMENTATION

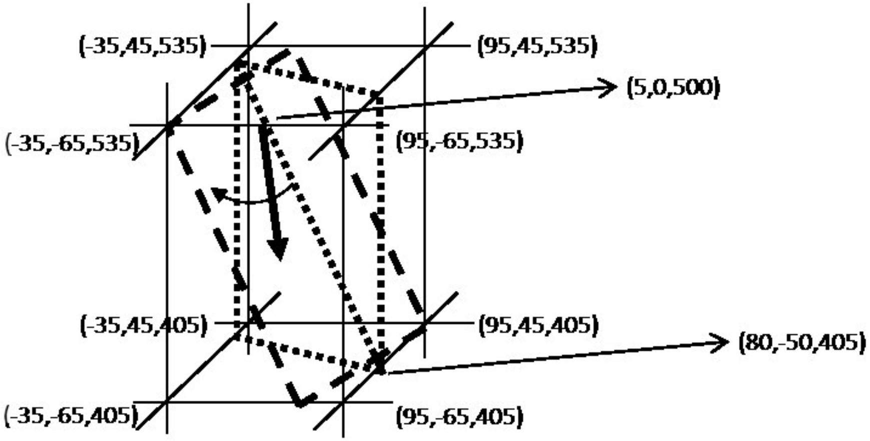
Equivalent Dipole Source Plane and Orientations










(-35,45,535)
(95,45,535)
(5,0,500)
(-35,-65,535)
(95,-65,535)
(-35,45,405)
(95,45,405)
(80,-50,405)
(-35,-65,405)
(95,-65,405)

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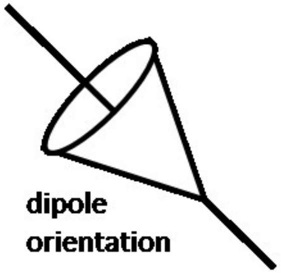
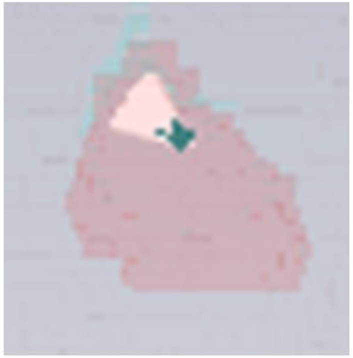
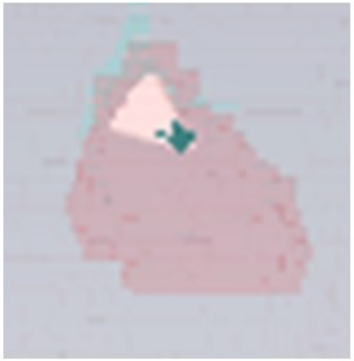
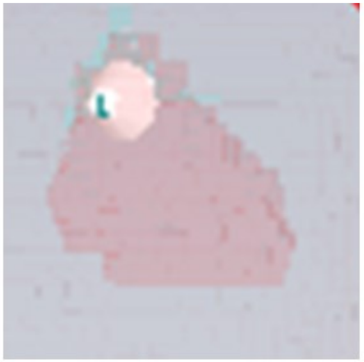
4. FIXED DIPOLE MODEL AND IMPLEMENTATION

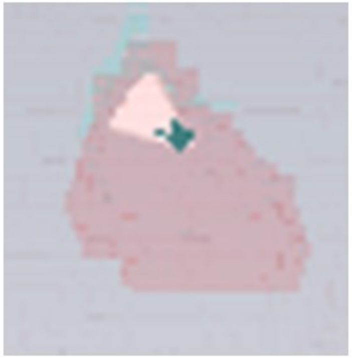
Equivalent Dipole Orientations

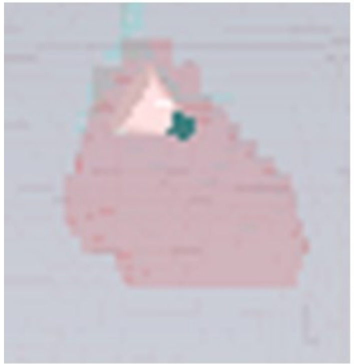

dipole
orientation

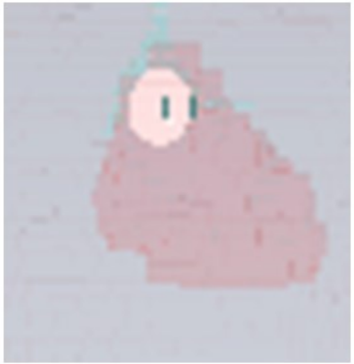

0ms

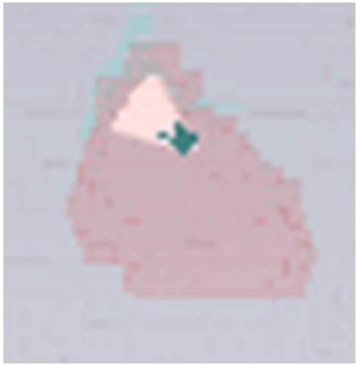

80ms

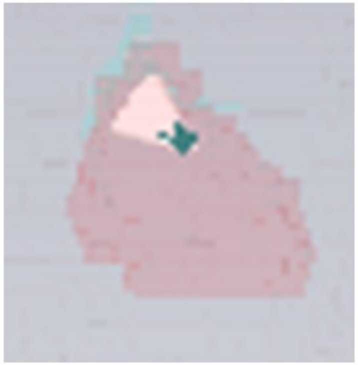

220ms

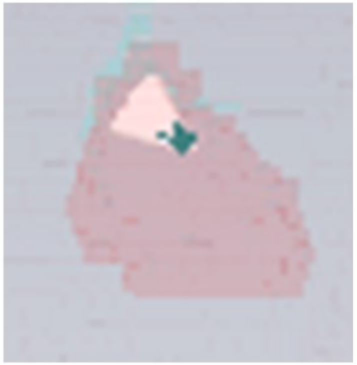

230ms


240ms


250ms


350ms


450ms


600ms

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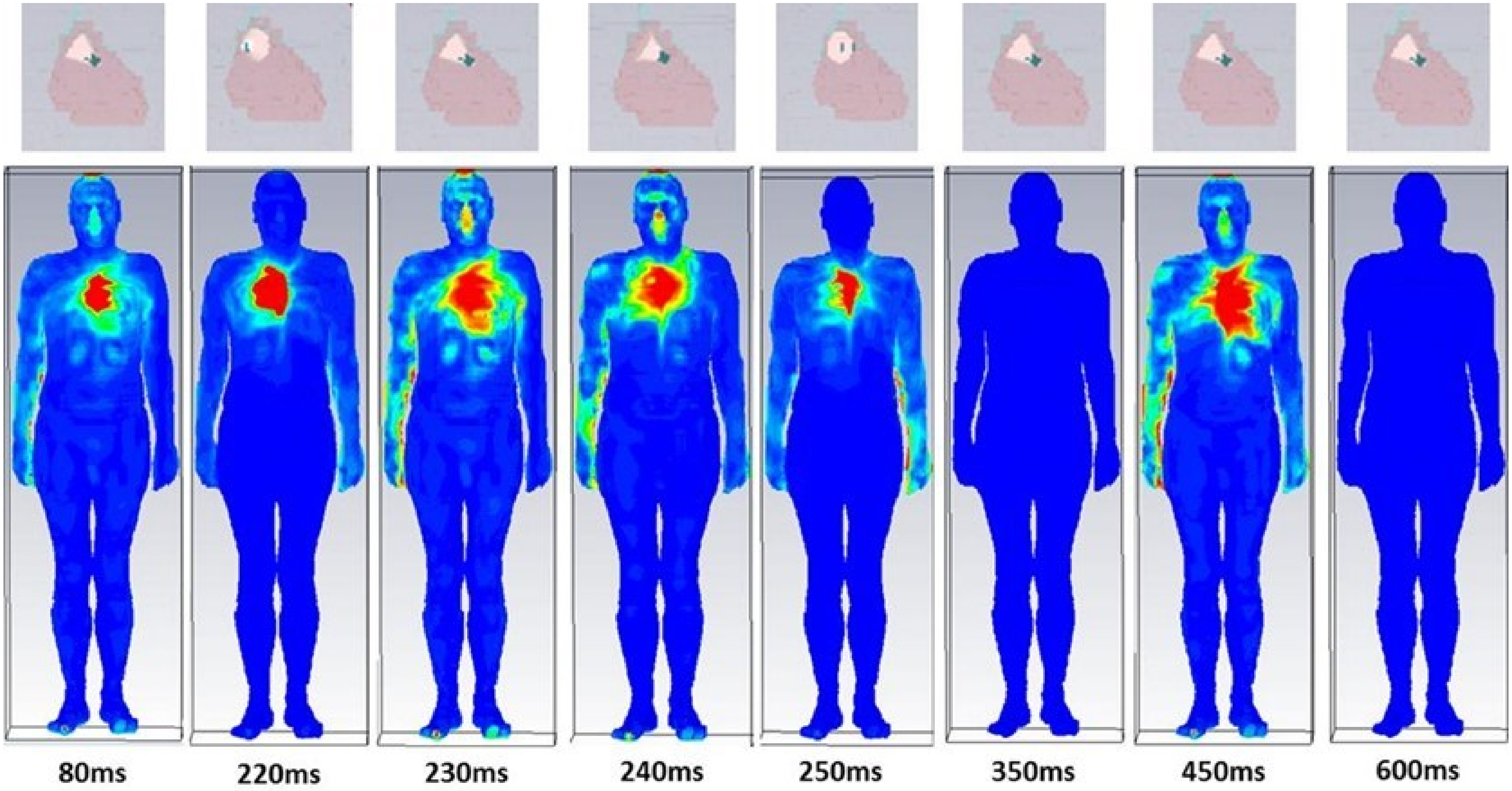
5. FIRST SIMULATION RESULTS

Max Body Surface Electric Field


80ms
220ms
230ms
240ms
250ms
350ms
450ms
600ms

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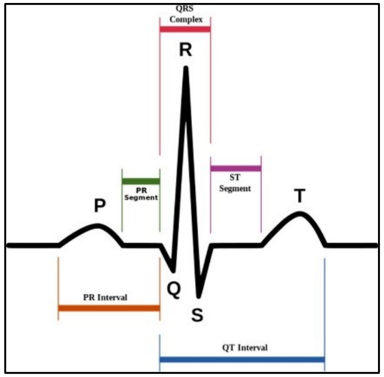
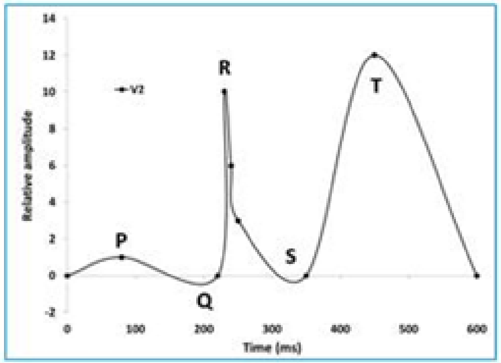
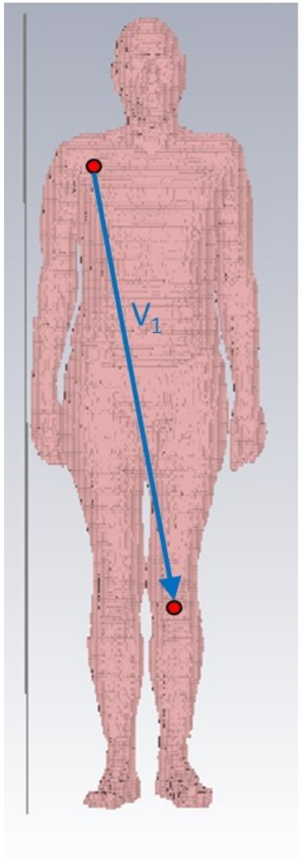
5. FIRST SIMULATION RESULTS

ECG Signal


QRS Complex
R
PR Segment
ST Segment
P
T
PR Interval
Q
S
QT Interval

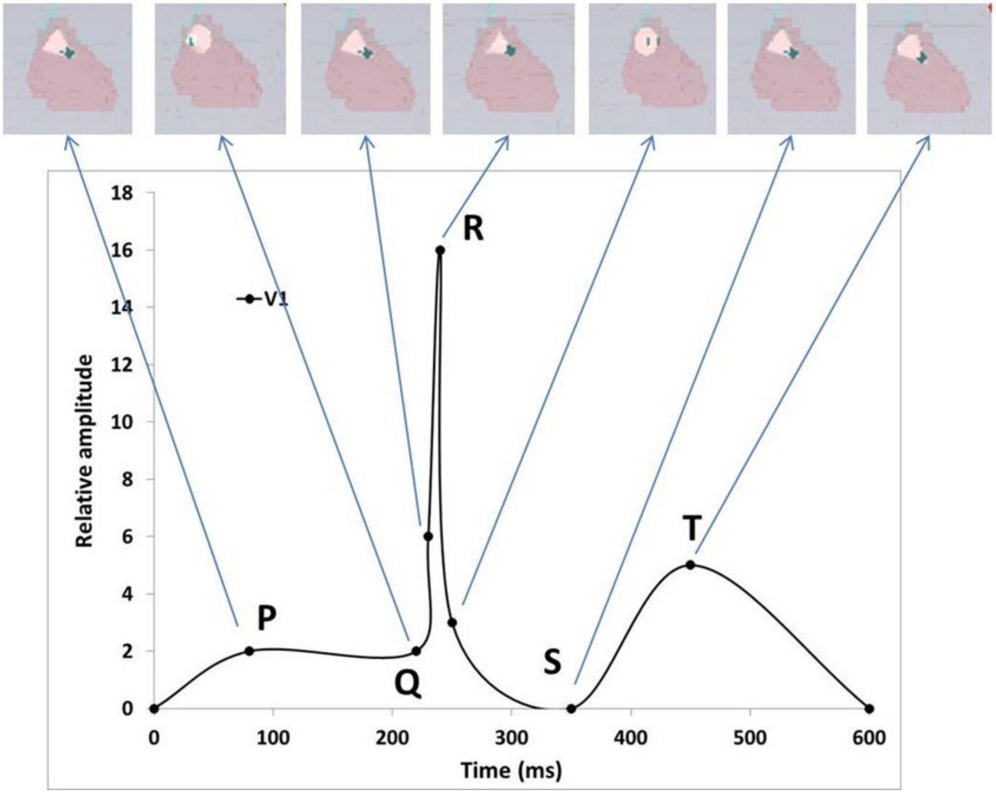
PQRST complex





Difference in 60Hz maximum body surface potential values

Fixed dipole position (sinus node in heart), varying amplitude and direction



6. CONCLUSION

To use a CST human voxel model for simulating ECG-like signals on the body

- A fixed dipole equivalent volume source is needed;
- This source is implemented as a sinusoidally excited current path;
- The maximum body surface electric field is recorded for different time stamps;
- The current path is rotated and changed in magnitude for every time stamp.

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BIO

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Hubregt J.Visser received the M.Sc. degree in electrical engineering from Eindhoven University of Technology, The Netherlands, in 1989. In 1990, after fulfilling his military service at TNO Physics and Electronics Laboratory, The Hague, The Netherlands, he joined the same laboratory as a civilian. He has participated in several projects concerning near-field antenna measurements, monolithic microwave integrated circuits design, and phased-array antenna design. In 2001 he joined TNO Science and Industry, Eindhoven, The Netherlands where he has been involved in antenna miniaturization projects. Since 2006 he has been part-time connected to the Holst Centre, Eindhoven, The Netherlands and in 2009 he joined the Holst Centre as an employee of imec. Here he is working on wireless energy transfer. In 2009 he obtained a Ph.D. from Eindhoven University of Technology, The Netherlands and Katholieke Universiteit Leuven, Belgium. He is part-time full professor at Eindhoven University of Technology where he teaches antenna theory. Hubregt is author of the books 'Array and Phased Array Antenna Basics' (Wiley, 2005), 'Approximate Antenna Analysis for CAD' (Wiley, 2009) and `Antenna Theory and Applications' (Wiley, 2012).

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ASPIRE
INVENT
ACHIEVE

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